JOURNAL OF AGRICULTURAL RESEARCH

Vol. XVI WASHINGTON, D. C., FEBRUARY 24, 1919 No. 8

APPLE-SCALD

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INTRODUCTION

The present paper gives a report of studies on the nature and control of apple-scald, including experiments upon the relation of orchard and storage conditions to the development of the disease. The literature upon the subject of apple-scald and the apparatus [1] and methods [2] used in these experiments have been rather fully reported in earlier publications.

RELATION OF CHARACTER OF FRUIT TO SCALD DEVELOPMENT

MATURITY

It is generally recognized that immature apples (*Malus sylvestris*) scald worse than mature ones.[3] A striking example of the fact was obtained in storage experiments at Wenatchee, Wash., in the winter of 1917–18. The apples of the different pickings were from the same trees and were approximately alike in every respect except in maturity. The first picking of the various varieties was made when the ground color of the fruit was very green and when the red varieties had developed but a slight blush, the second picking when the ground color was beginning to show yellow and most of the apples of the red varieties had become deeply colored. The apples were stored in commercial box packages. One or more boxes of fruit were used under each storage condition of every experiment. The final notes for the Rome Beauty and Stayman Winesap were taken on March 19 and for the other varieties on March 12. The Rome Beauty and Stayman Winesap were allowed to stand in cellar storage five days before the notes were taken, and the other varieties were held in a laboratory at 20° C. for four days before note taking. The results are given in Table I.

In all cases there was less scald on the well-colored than on the poorly colored fruit, and in most cases fruit picked at the proper maturity was almost entirely free from scald.

[1] BROOKS, Charles, and COOLEY, J. S. TEMPERATURE RELATIONS OF APPLE ROT FUNGI. *In* Jour. Agr. Research, v. 8, no. 4, p. 139–164, 25 fig., 3 pl. 1917.

[2] ——— ——— EFFECT OF TEMPERATURE, AERATION, AND HUMIDITY ON JONATHAN-SPOT AND SCALD OF APPLES IN STORAGE. *In* Jour. Agr. Research, v. 11, no. 7, p. 287–318, 23 fig., pl. 32–33. 1918. Literature cited, p. 316–317.

[3] RAMSAY, H. J., MCKAY, A. W., MARKELL, E. L., and BIRD, H. S. THE HANDLING AND STORAGE OF APPLES IN THE PACIFIC NORTHWEST. U. S. Dept. Agr. Bul. 587, 32 p., 7 col. pl. 1917.

Journal of Agricultural Research, Washington, D. C.
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Vol. XVI, No. 8
Feb. 24, 1919.
Key No. G-173

TABLE I.—*Effect of maturity of fruit upon susceptibility to apple-scald*

Experiment No.	Variety.	Storage condition.	Date of picking.	Maturity at time of picking.	Percentage showing scald March, 1918.
1	Rome Beauty	Cold storage continously.	Oct. 8	Rather immature	20
			Oct. 24	Well colored	0
2	...do	Cold storage 2 months, then in cellar storage.	Oct. 8	Rather immature	40
			Oct. 24	Well colored	0
3	...do	Cold storage till January 25, then in cellar storage.	Oct. 8	Rather immature	95
			Oct. 24	Well colored	5
4	Stayman Winesap	Cold storage continuously.	Oct. 9	Rather immature	65
			Oct. 25	Highly colored	0
5	...do	Cold storage 2 months, then in cellar storage.	Oct. 9	Rather immature	30
			Oct. 25	Highly colored	0
6	...do	Cold storage till January 25, then in cellar storage.	Oct. 9	Rather immature	90
			Oct. 25	Highly colored	5
7	Baldwin	Cold storage till February 11, then in cellar storage.	Sept. 27	Rather immature	50
			Oct. 30	Well colored	0
8	Bellflower	...do	Sept. 22	Immature	90
			Oct. 2	Well colored	40
			Oct. 1	Rather overripe	30
9	Grimes, heavily irrigated.	...do	Sept. 22	Color green	95
			Oct. 2	Color yellowing	95
			Oct. 12	Rather overripe	30
10	Grimes, lightly irrigated.	...do	Sept. 22	Color green	50
			Oct. 2	Color yellowing	25
			Oct. 12	Rather overripe	10

Scald prevention on eastern-grown fruit is apparently not as readily accomplished. In an earlier report[1] the writers found little contrast in susceptibility to scald on eastern Grimes apples, a part of which were picked on August 11, when the fruit was quite green, a part August 28, when the apples were in condition for commercial picking, and a part on September 21, when the fruit was quite yellow. This experiment was repeated in 1917 on Grimes apples from Vienna, Virginia. The first picking was made on August 21, when the ground color of the fruit was green, and a second picking on September 14, when the apples were becoming yellow and were at their best for commercial picking. The fruit was stored in moist chambers at various temperatures[2] in special storage boxes at Washington, D. C., and notes taken at various times on the development of scald. The results are given in figure 1.

[1] BROOKS, Charles, and COOLEY, J. S. EFFECT OF TEMPERATURE, AERATION, AND HUMIDITY ON JONATHAN-SPOT AND SCALD OF APPLES IN STORAGE. In Jour. Agr. Research, v. 11, no. 7, p. 287–318, 23 fig., pl. 32–33. 1917. Literature cited, p. 316–317.

[2] Temperature equivalents: 0° C.=32° F.; 5° C.=41° F.; 15° C.=59° F.; 20° C.=68° F.; 25° C.=77° F.; 30° C.=86° F.

The results at the higher temperature are in agreement with those of the preceding year, indicating little difference in susceptibility to scald between the well-colored and poorly colored Grimes, but at 0° the latter finally developed about twice as much scald as the former, giving further evidence of the greater susceptibility of green fruit when held at temperatures low enough to prevent ripening.

EASTERN AND WESTERN FRUIT

Experiments were made to determine the relative susceptibility to scald of eastern and western Grimes of practically the same degree of maturity. The western Grimes were shipped from Wenatchee, Wash., to Washington, D. C., in well-iced pony refrigerators. The eastern apples were placed in storage the day after picking. Part of the western apples were from trees that had been heavily irrigated. These apples were large, most of them 3 to 3¼ inches in diameter. The remainder of the western apples were from trees that had received very little irrigation and were small, ranging from 2¼ to 2½ inches in diameter. Most of the eastern apples were from 2½ to 2¾ inches in diameter. All of the apples were held in moist chambers in the storage boxes already mentioned. Ten apples were used in each test. The results are shown in figure 2.

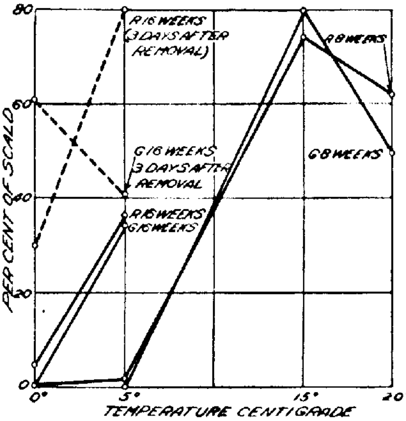

FIG. 1.—Graphs showing the effect of maturity upon susceptibility of Grimes apples to scald. The graphs show the percentage of scald on the two lots of apples at the ends of 8 and 16 weeks, respectively. The ones marked "G" give the results on the fruit picked on August 21 and those marked "R" the results on the fruit picked September 14. The dotted lines show the percentage of scald after the apples had been removed from storage and had stood in the laboratory at a temperature of 20° C. for three days.

The heavily irrigated western apples were somewhat less susceptible and the lightly irrigated ones much less susceptible to the disease than the eastern apples. While the eastern and western fruit did not receive exactly the same treatment, the results as a whole indicate that western Grimes apples from a region of intense sunlight are less susceptible to scald than eastern apples of practically the same maturity.

EFFECT OF IRRIGATION UPON SUSCEPTIBILITY TO SCALD

A study of figure 2 gives some evidence that apples from heavily irrigated trees are more susceptible to scald than those from lightly irrigated ones. In another experiment heavily and lightly irrigated Grimes apples of the same maturity were held in commercial cold storage at Wenatchee, Wash., till February 11, and then in cellar storage till March 12. The apples were stored in commercial box packages, two or more boxes of fruit being used under each storage condition of each experiment. The results are given in Table II.

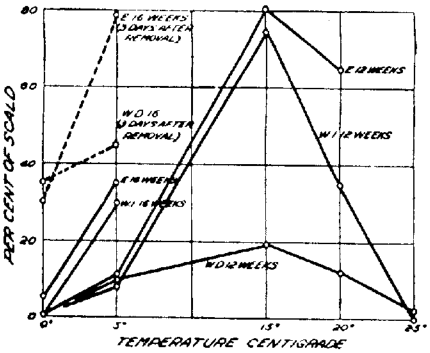

FIG. 2.—Graphs showing the relative susceptibility to scald of eastern and western Grimes apples. The graphs show the percentage of scald at the end of the given week. Those marked "E" give the results on the eastern apples, those marked "WI" the results on the heavily irrigated western apples, and those marked "WD" the results on the western apples receiving practically no irrigation. The dotted lines show the percentage of scald after the apples had been removed from storage and had stood in the laboratory at a temperature of 20° C. for three days.

Under all of the different conditions of picking the heavily irrigated apples showed a greater susceptibility to scald than the lightly irrigated ones, the former averaging about twice as much scald as the latter. There were more large apples in the heavily irrigated lots than in the lightly irrigated ones, but this fact seemed to have but little influence upon the results, as heavily irrigated apples of a particular size were scalded worse than lightly irrigated ones of the same size.

TABLE II.—*Influence of irrigation upon susceptibility of apples to scald*

Experiment No.	Variety and condition.	Percentage scald.	
		Heavily irrigated.	Lightly irrigated.
1	Rather poorly colored Grimes apples picked on September 22	95	50
2	Fairly well colored Grimes apples picked on October 2	95	25
3	Rather overripe Grimes apples picked on October 12	30	10

RELATION OF TEMPERATURE TO APPLE SCALD

A rather full discussion of the relation of temperature to apple scald has already been published by the writers.[1] The results given in figures 3 to 10, inclusive, of this paper confirm and extend the statements of the earlier report. As in the earlier experiments, the apples were stored in moist chambers and ten or more apples were used in each test. The experiment was started on August 21.

A study of the figures shows that the optimum for scald production is approached at 15° C. and the maximum apparently reached at 25°. With all of the different varieties tested scald failed to develop at either 25° or 30°. This fact gives evidence that scald is not purely an old-age characteristic and that it can not be mainly due to the accumulation of carbon dioxid, for both the aging and respiring of the fruit are accelerated by these high temperatures.

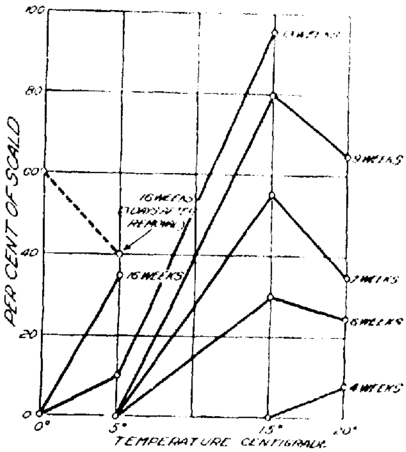

FIG. 3.—Graphs showing the effects of temperature on apple scald at the end of 4, 6, 7, 9, 13, and 16 weeks. The dotted graph shows the amount of scald that was evident after removal from storage at the end of the given week and holding the apples at 20° C. for 5 days. The apples were Grimes from Vienna, Va., picked on August 20.

A comparison of the results at 15° and 20° shows that in several cases (fig. 3, 4, 5) there was a shift in the optimum as the experiment advanced. Scald appeared first at 20° and for several weeks was worse at this temperature than at 15°, but later became decidedly worse at the lower temperature.

A particular degree of scald usually developed 8 to 12 weeks later at 5° than at 15° and several weeks later at 0° than at 5°. Scald was worse at 5° than at 0° in all cases except with the very green Grimes (fig. 3) and fairly green Rome Beauty (fig. 8).

In all of the above temperature experiments the apples were placed in moist chambers. The relative humidity was practically 100 per cent, the carbon dioxid from 1 to 3 per cent, and there was practically no air movement. In all of the various experiments and at all of the different temperatures similar apples were held in open containers in an atmosphere having less than 0.5 per cent of carbon dioxid, a relative humidity

[1] BROOKS, Charles, and COOLEY, J. S. EFFECT OF TEMPERATURE, AERATION, AND HUMIDITY ON JONATHAN-SPOT AND SCALD OF APPLES IN STORAGE. *In* Jour. Agr. Research, v. 11, no. 7, p. 287–318, 23 fig., pl. 31–33. 1917. Literature cited, p. 316–317.

of 85 to 95 per cent and an air movement of ⅛ to ¼ mile per hour. With two exceptions, both in the case of very green apples at 0°, the fruit held in the open remained free from scald to the end of the various experiments, indicating that other factors are even more important than temperature, and that a solution of the problem of scald prevention should be found either in the composition or rate of movement of the storage air.

INFLUENCE OF AIR COMPOSITION UPON APPLE-SCALD

HUMIDITY

It did not seem probable that a reduction in the relative humidity from 100 per cent to an average of 90 per cent as mentioned above could be responsible for the complete elimination of scald, but it seemed desirable to have further tests on the point. Table III gives the results of various experiments in which the humidity was varied, with little or no change in temperature or other environmental factors. In cases where it was necessary to introduce outside air this was brought to the temperature of the fruit before being allowed to come in contact with it.

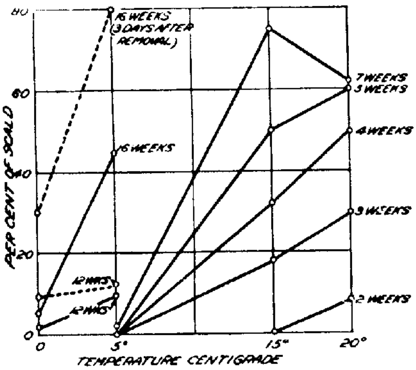

FIG. 4.—Graphs showing the effects of temperature on apple-scald at the end of 2, 3, 4, 5, 7, 12, and 16 weeks. The dotted graphs show the amount of scald that was evident after removal from storage at the end of the given week and holding the apples at 20° C. for 3 days. The apples were from the same trees as those of figure 3, but were picked 24 days later, on September 13, and the experiment was started on September 14.

A study of the results from the various experiments reported in Table III shows that, in general, only about half as much scald developed on apples exposed to dry air as on those exposed to saturated air. It does not seem, however, that high humidity can be the primary cause of the disease, for in no case was scald entirely prevented by dryness, and in every case where the air was stirred, the disease was practically eliminated, even in the presence of the highest humidities. The withering of the apples in the dry air makes this method of partial prevention an impractical one, and the fact that the disease can be prevented without drying naturally raises the question whether the beneficial effects noted from the use of moisture-absorbing agents may not be at least partly due to their power to absorb some substance other than water, or to the fact that the evaporation of the water assists in the elimination of some distinctly harmful substance.

TABLE III.—*Influence of humidity upon apple-scald*

Experiment No.	Treatment.	Percentage of scalds.				
		Grimes at 15° C.	York Imperial.		Arkansas	
			At 2½° C.	At 0° C.	At 2½° C.	at 0° C.
A1	Air saturated, passed slowly over wet filter paper and through wash bottles of water	50				...
A2	Same as No. 1, but air-dry, bubbled slowly through sulphuric acid and glycerin	23		...		...
A3	Same as No. 1, but air in motion at rate of about ⅛ mile per hour	0		...		...
B1	Air saturated, wet filter paper in bottom of container and the entering air bubbled through water	10	...	...	...	...
B2	Air-dry, calcium chlorid in bottom of container and the entering air passed over calcium chlorid and bubbled through glycerin	5		...	...	...
B3	Apples in open, exposed to air having a relative humidity of 85 to 95 per cent and a constant movement of ⅛ to ¼ mile per hour	0	...			
C1	Saturated air, renewed slowly	...	20	4	60	55
C2	Same as No 1, but air-dry	...	8	8	32	25
C3	Same as No. 1, but with air circulated by air pump	...	0		7	...
C4	Same as No. 2, but air renewed 10 to 15 times more rapidly	...	0		5	
C5	Apples in open package	...	0	0	0	...

EXPERIMENT A.—Grimes apples of the lot described in the legend for figure 5 were stored at 15° C. for 7 weeks. In all three cases cited the carbon dioxid of the storage air was held at 3 to 4 per cent by the constant introduction of air containing 3 per cent of this gas. The rate of renewal was such that a volume of air equal to that in the container was carried in once in every 24 hours. In No. 3, however, in addition to this slight air movement, the air was kept in constant motion at a rate somewhat less than ⅛ mile per hour by means of a closed-circuit connection with an air pump.

EXPERIMENT B.—Grimes apples of the same lot as mentioned in Experiment A were used, but they were held in commercial cold storage for eight weeks before the experiment was started. The contrasted results were obtained after three weeks' storage at 15° C. With Nos. 1 and 2 the apples were held in unsealed jars and fresh air drawn in rapidly for about 10 minutes every second day, the volume of air carried through being several times that of the container.

EXPERIMENT C.—The apples used in this experiment were York Imperial and Arkansas of tle same lots as described in the legends for figures 9 and 10, respectively. The contrasted results were obtained after 20 weeks of storage at the temperatures given. With No. 1 the apples were held in a closed container and fresh air introduced continuously at a rate such that a volume of air equal to that in the container was carried in once in 24 hours. The air was kept saturated with moisture by means of wet filter paper in the bottom of the jar and by bubbling the entering air through water. No. 2 was handled exactly as No. 1 with the exception that calcium chlorid was placed in the bottom of the jar and the entering air was passed over calcium chlorid and bubbled through glycerin. No. 3 was treated the same as No. 1 with the exception that the air of the container was kept in motion at a rate somewhat less than ⅛ mile per hour by means of a closed-circuit connection with a rotary air pump. No. 4 had practically the same degree of dryness as No. 2 (evidenced by the withering of the apples), but this was secured by drawing in fresh air at a rate 10 to 15 times faster than in the case of No. 2 without using any drying agent either in the container or with the entering air. With No. 5 the apples were held in the open, exposed to air moving at the rate of ⅛ to ¼ mile per hour, and having a relative humidity at 2½° C. of 70 to 80 per cent and at 0° C. of 85 to 90 per cent.

CARBON DIOXID

Perhaps the most natural assumption in regard to apple-scald is to consider carbon dioxid as the responsible agent. The writers have made numerous experiments looking to the establishment of this hypothesis, but these have resulted in proof that carbon dioxid is not a causal agency in the production of the disease. The nature and results of the experiments are shown in figure 11.

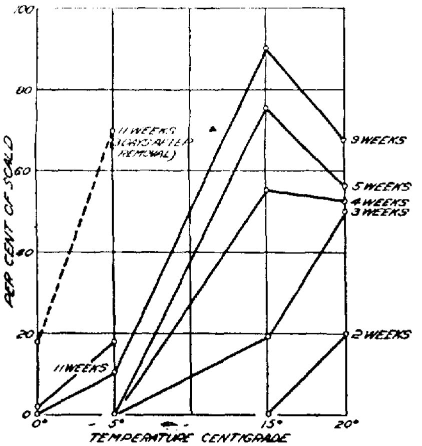

FIG. 5.—Graphs showing the effects of temperature on apple-scald at the end of 2, 3, 4, 5, 9, and 11 weeks. The dotted graph shows the amount of scald that was evident after removal from storage at the end of the given week and holding the apples at 20° C. for 3 days. The apples were of the same lot as those of figure 4 and were picked on the same day, but were held in commercial cold storage from September 14 to October 15, and were transferred to the storage boxes for the above experiment on the latter date. The weeks of storage as given on the graphs are counted from October 15, the time of starting the special experiment.

The results give conclusive evidence that an accumulation of carbon dioxid is not responsible for the production of scald. In 2 of the 10 different tests the amount of scald was slightly decreased with a decrease in amount of carbon dioxid, but with the other 8 it was either unchanged or decidedly increased. The results as a whole indicate that, while an accumulation of the gas may sometimes be an accompaniment of apple-scald, carbon dioxid itself really tends to prevent rather than aggravate the development of the disease.

TABLE IV.—*Effect of storing apples in carbon dioxid for short periods on development of scald*

Experiment No.	Treatment	Percentage of scald.
A1. .	Apples in 100 per cent of carbon dioxid at 30° C. for 3 days, then at 15° in moist chamber for 8 weeks.	0
A2. .	Apples in moist chamber at 15° continuously for the above-mentioned periods without carbon-dioxid treatment.	15
B1. .	Apples in 100 per cent of carbon dioxid at 15° C. for 6 days, then in moist chamber at 15° for 11 weeks.	0
B2. .	Same as B1, but continuously in moist chamber without carbon-dioxid treatment.	40

Apples stored in higher percentages of carbon dioxid than those given in figure 11 soon developed a disagreeable alcoholic taste, but if they were removed after a few days' exposure to the gas they were found to have but little, if any, of this objectionable taste and to have developed a decided resistance to scald. The results of two experiments of this sort are given in Table IV. The apples were Grimes of the lot described in the legend of figure 7.

In the first experiment the taste of the apples was slightly affected by the exposure to carbon dioxid, but in the second experiment the apples exposed to carbon dioxid had as good a taste as those held continuously in moist chambers. In both cases the treated apples developed color in storage very much more slowly than the untreated. It would seem from the results that the carbon dioxid had produced a very decided inhibition of the activities of the apple, and thus led to scald prevention.

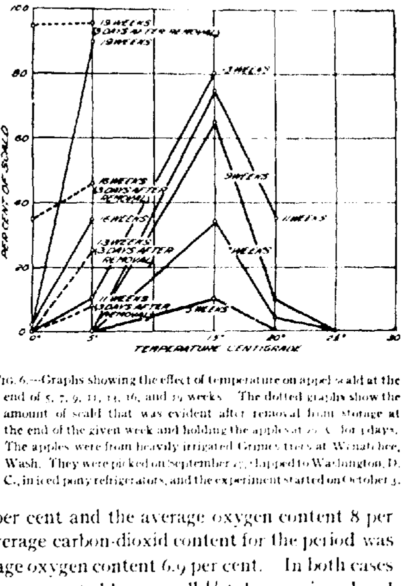

FIG. 6.—Graphs showing the effect of temperature on apple scald at the end of 5, 7, 9, 11, 13, 16, and 19 weeks. The dotted graphs show the amount of scald that was evident after removal from storage at the end of the given week and holding the apples at 20° C. for 3 days. The apples were from heavily irrigated Grimes trees at Wenatchee, Wash. They were picked on September 27, shipped to Washington, D. C., in iced pony refrigerators, and the experiment started on October 3.

OXYGEN

In the experiments with carbon dioxid reported in figure 11 the oxygen of the air was usually slightly below normal, but with the exception of (c) and (d) under B there was never a deficiency of more than 1 or 2 per cent. With (c) the average carbon dioxid content of the air after the first two weeks of the experiment was 6 per cent and the average oxygen content 8 per cent, while with (d) the average carbon-dioxid content for the period was 14.5 per cent and the average oxygen content 6.9 per cent. In both cases any pressure or suction was prevented by a small U-tube opening closed with oil. The results given in *figure 11* give no evidence that these deficiencies in oxygen had any tendency either to increase or decrease the amount of scald. The apples seemed normal at the end of the experiment, with the exception of a very faint trace of an aromatic musty flavor.

In an earlier paper[1] experiments were reported indicating that slight increases (increasing the percentage from 21 to 24) in the oxygen content

[1] BROOKS, Charles, and COOLEY, J. S. EFFECT OF TEMPERATURE, AERATION, AND HUMIDITY ON JONATHAN-SPOT AND SCALD OF APPLES IN STORAGE. *In* Jour. Agr. Research, v. 11, no. 7, p. 287–318, 23 fig., pl. 32–33. 1917. Literature cited, p. 316–317.

of the air also had no appreciable effect upon the development of scald. During the past season this test was repeated, using higher percentages of oxygen. The air was slowly renewed in the manner described in Table III and was not stirred. The temperature was 15° C., except E, which was 0° C. Five apples were used in each test. The results are given in Table V.

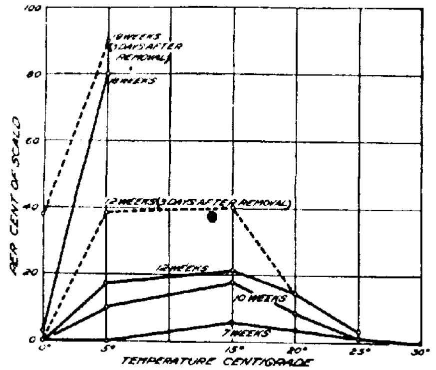

FIG. 7.—Graphs showing the effect of temperature on apple-scald at the end of 7, 10, 12, and 18 weeks. The dotted graphs show the amount of scald that was evident after removal from storage at the end of the given week and holding the apples at 20° C. for 3 days. The apples were from very lightly irrigated Grimes trees at Wenatchee, Wash. They were picked on October 3, shipped to Washington, D. C., in iced pony refrigerators, and the experiment started on October 9.

The results have not been consistent. An increase in the percentage of oxygen in the air gave a decided decrease in the amount of scald on Newtown, Pippin, and Rome Beauty apples that had been held several months in cold storage before the experiment was started (B and C), but failed to do so on Grimes apples that were exposed in similar atmospheres from the beginning of their storage life (A, D, and E). As a whole, the results are in decided contrast with the uniformly beneficial effects reported later as resulting from air circulation.

TABLE V.—*Influence of increase in oxygen upon the development of apple-scald*

Experiment No.	Variety and treatment.	Composition of air supplied.	Percentage of scald.
A	Grimes apples of lot described in legend for figure 3. Results after 8 weeks.	4 per cent of carbon dioxid, 28 per cent of oxygen.	45
		4 per cent of carbon dioxid, oxygen normal.	40
		Normal air (21 per cent of oxygen)	65
B	Newtown Pippin from Hood River, Oreg. In cold storage till Jan. 26. Experiment started on this date and ended 12 weeks later.	32 per cent of oxygen	10
		Normal air (21 per cent of oxygen)	80
C	Rome Beauty from Vienna, Va. In cold storage till Jan. 26. Experiment started on this date and ended 12 weeks later.	do	5
			65
D	Grimes apples from Vienna, Va., picked Aug. 26, 1918. The experiment was started Aug. 27 and the results obtained after 8 weeks.	do	45
			50
E	Same as D, but at 0° C. and the results obtained after 16 weeks.	do	35
			38

AIR MOVEMENT AS A PREVENTIVE OF SCALD

AIR CIRCULATION

The value of aeration in the prevention of apple-scald was pointed out by the writers in an earlier report[1] and the previous data of the present paper have given confirmatory evidence on this point. Other experiments were made in which the effect of air circulation apart from air renewal was tested. The air movement was obtained by connecting the containers to rotary air pumps. A continuous circulation in a closed circuit was thus secured. The rate of movement was less than $\frac{1}{2}$ and probably more than $\frac{1}{4}$ mile per hour. (See Table III for methods used in keeping the composition of the air constant.) The results are given in Table VI.

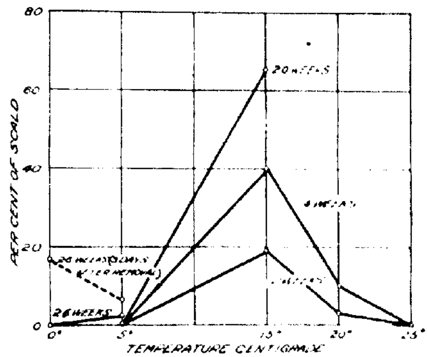

FIG. 8.—Graphs showing the effect of temperature on apple-scald at the end of 12, 14, 20, and 26 weeks. The dotted graph shows the amount of scald that was evident after removal from storage at the end of the given week and holding the fruit at 20° C. for 3 days. The appels were Rome Beauty from Vienna, Va. They were picked on October 3, and the experiment was started October 4.

The results are striking. With all of the different air compositions and all of the different lots of apples a gentle air movement practically eliminated scald, while similar apples held in stagnant air of like composition became badly scalded. The writers attribute the beneficial effects of the air movement to the breaking up of layers of dead air adjacent to the skin of the apple, thus disseminating harmful gases that might otherwise hang in the tissues of the apple.

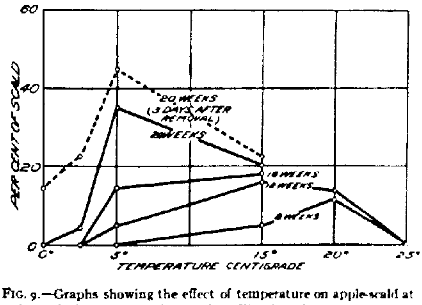

FIG. 9.—Graphs showing the effect of temperature on apple-scald at the end of 8, 12, 16, and 20 weeks. The dotted graph shows the amount of scald that was evident after removal from storage at the end of the given week and holding the fruit at 20° C. for 3 days. The apples were York Imperial from Vienna, Va. They were picked and packed in barrels on October 2 and placed in commercial cold storage the following day. They were removed from storage on December 4 and the above experiment started the same day.

[1] BROOKS, Charles, and COOLEY, J. S. EFFECT OF TEMPERATURE, AERATION, AND HUMIDITY ON JONATHAN-SPOT AND SCALD OF APPLES IN STORAGE. *In* Jour. Agr. Research, v. 11, no. 7, p. 287–318, 23 fig., pl. 32–33. 1917. Literature cited, p. 316–317.

TABLE VI.—*Effect of air movement upon apple-scald*

Experiment No.	Variety and treatment.	Treatment.	Percentage of scald. Grimes.	Arkansas.	York Imperial.
A	Grimes apples of lot described in figure 3 after 8 weeks' storage at 15° C.	With 4 per cent of carbon dioxid; air stirred.	0	......	......
		With 4 per cent of carbon dioxid; air not stirred.	40	......	......
		With 2 per cent of carbon dioxid; air stirred.	2	......	......
		With 2 per cent of carbon dioxid; air not stirred.	60	......	......
		Air; air (0.2 per per cent of carbon dioxid and 0.5 per cent of oxygen) stirred.	3	......	......
		Air; air not stirred.	65	......	......
		Apples in open; air movement ⅛ to ¼ mile per hour.	2	......	......
		Apples in moist chamber; air not stirred.	80	......	......
B	York Imperial and Arkansas apples of lots described in figures 9 and 10. Results obtained after 20 weeks' storage at 2.5° C.	Apples in open; air movement ⅛ to ¼ mile per hour.	......	3	0
		Apples in moist chamber; air not stirred.	......	80	20
		With 3 per cent of carbon dioxid; air stirred.	......	15	0
		With 3 per cent of carbon dioxid; air not stirred.	......	80	5
		Normal air; air stirred.	......	7	0
		Normal air; air not stirred.	......	60	15
C	Grimes apples of lot described in figure 5 after 6 weeks at 15° C.	Apples in open; air movement ⅛ to ¼ mile per hour.	0	......	......
		Apples in moist chamber; air not stirred.	75	......	......
		With 6 per cent of carbon dioxid; air stirred.	5	......	......
		With 6 per cent of carbon dioxid; air not stirred.	18	......	......
		With 3 per cent of carbon dioxid; air stirred.	1	......	......
		With 3 per cent of carbon dioxid; air not stirred.	50	......	......
		Air (air with 14.5 per cent of carbon dioxid, 6 per cent of oxygen); stirred.	1	......	......
		Air (air with 0.6 per cent of carbon dioxid, 0.8 per cent of oxygen); stirred.	3	......	......
		Air not stirred; 1 per cent of carbon dioxid.	60	......	......

INTERMITTENT AERATION

In the experiments reported in Table VI the air was kept in constant circulation, but this continuitly of the movement is apparenty not essential to the prevention of apple-scald. In an earlier paper [1] experi-

[1] BROOKS, Charles, and COOLEY, J. S. EFFECT OF TEMPERATURE, AERATION, AND HUMIDITY ON JONATHAN-SPOT AND SCALD OF APPLES IN STORAGE. *In* Jour. Agr. Research, v. 11, no. 7, p. 287–318, 23 fig., pl. 31–33. 1917. Literature cited, p. 316–317.

ments were reported in which scald was entirely prevented on Grimes apples at 15° C. by drawing the air rapidly through the container for a 10-minute period three times a week. During the past season this experiment was repeated but at 5° C. and with York Imperial and Arkansas apples. The amount of apple-scald developed after 20 weeks is given in Table VII.

TABLE VII.—*Effect of intermittent aeration on apple-scald*

Experiment No.	Treatment	Percentage of scald. Arkansas.	Percentage of scald. York Imperial.
1	Air renewed continuously, a volume of fresh air equal to that in the container being passed in every 48 hours	85	20
2	Air renewal every second day, a volume of fresh air equal to twice that in the container being passed in in 10 minutes	50	40

The control of apple-scald was not as complete as in the earlier experiments, but a limited amount of air had a greater beneficial effect when passed into the container within a period of 10 minutes than when distributed over a period of 48 hours.

With a slow rate of air movement the amount of scald was found to vary with the length of time the movement was continued, as shown in the results given in Table VIII.

TABLE VIII.—*Relation of period of aeration to the development of apple-scald*

Experiment No.	Variety and previous treatment.	Treatment.	Percentage of scald.
A1	Grimes apples of same lot as described in legend for figure 6 after 9 weeks' storage at 15° C.	In moist chamber continuously	65
A2	.....do	In open continuously; air movement 1/8 to 1/4 miles per hour.	0
A3	.....do	Alternately 2 weeks with same treatment as No. 1, then 2 weeks as No. 2.	8
B1	Grimes apples of same lot as described in legend for figure 7 after 18 weeks' storage at 0° C.	In moist chamber continuously	37
B2	.....do	In open continuously; air movement 1/8 to 1/4 miles per hour.	0
B3	.....do	Same treatment as No. 1 for 8 weeks, then same as No. 2.	20

The rate of air movement was probably but little above the minimum for scald prevention, and the results show a direct relation between the duration of the movement and the amount of apple-scald.

TEMPERATURE CHANGES AS A MEANS OF AERATION

Apples held at a constant temperature have usually scalded worse than those exposed to temperature changes, the beneficial effects of the fluctuating temperature apparently being due to the aeration of the apple tissue thus obtained. Experimental results on this point are given in Table IX.

All of the apples were held in moist chambers and were therefore poorly aerated.

TABLE IX.—*Influence of temperature changes upon apple scald*

Experiment No.	Variety and previous treatment.	Temperature.	Percentage of scald.
1	Rather immature Grimes apples of lot described in figure 3.	At 5° C. continuously for 16 weeks	38
		At 0° C. continuously for 16 weeks	05
		At 5° C. for 4 weeks; then at 0° C. for 12 weeks.	6
		At 0° C. for 4 weeks; then at 5° C. for 12 weeks.	20
		At 5° C. for 8 weeks; then at 0° C. for 8 weeks.	10
		At 0° C. for 8 weeks; then at 5° C. for 8 weeks.	60
2	Grimes apples of lot described in figure 7.	At 5° C. continuously for 12 weeks	40
		At 0° C. continuously for 12 weeks	0
		At 5° C. for 8 weeks; then at 0° C. 4 weeks.	5
		At 0° C. for 8 weeks; then at 5° C. 4 weeks.	35
3	Grimes apples of lot described in figure 6 after 9 weeks of storage.	At 15° C. continuously	65
		Alternately 2 days each at 5° C. and 25° C. (Average temperature, 15° C.)	25

The results in experiments 1 and 2 indicate that the amount of scald was decreased by moving the apples from one temperature to another during the first weeks of storage. The apples were given no aeration at the time of change, and a probable explanation of the beneficial effects resulting from shifting the apples from one temperature to another seems to be some sort of renovation of intercellular air conditions accompanying the temperature changes in the tissues. The apples stored first at 5° and then at 0° had less scald and were of better quality than those stored first at 0° and then at 5° or than those stored continuously at 0°.

In experiment 3 the apples were held part of the time at a temperature (25° C.) that has been proved to be too high for the production of scald. Other experiments have been made in which aeration has been combined with high temperature with decidedly beneficial results in scald prevention. In an earlier paper [1] an instance was reported in which scald

[1] BROOKS, Charles, and COOLEY, J. S. EFFECT OF TEMPERATURE, AERATION, AND HUMIDITY ON JONATHAN-SPOT AND SCALD OF APPLES IN STORAGE. *In* Jour. Agr. Research, v. 11, no. 7, p. 287–318, 23 fig., pl. 32–33. 1917. Literature cited, p. 316–317.

was prevented by one thorough aeration for 24 hours at 20° C. and then by storing at 5° C. In the winter of 1917–18 some striking results on this point were again obtained.

Of two lots of Grimes apples from Wenatchee, Wash., picked from the same trees and placed in commercial cold storage at the same time, one lot consisting of 10 boxes was brought out twice for aeration and note-taking, remaining at a temperature of 20° C., the first time for 4 hours (after 5 weeks' storage), and the second time for 48 hours (after 10 weeks' storage). The second lot consisting of 12 boxes was left in cold storage continuously. At the end of 17 weeks' storage the amount of scald on the fruit in the former lot ranged from 5 to 30 per cent, averaging 15.5 per cent, while that in the latter lot ranged from 50 to 80 per cent, averaging 65 per cent. The two aerations at laboratory temperature were apparently sufficient to reduce the scald to one-fourth that on apples held continuously in cold storage.

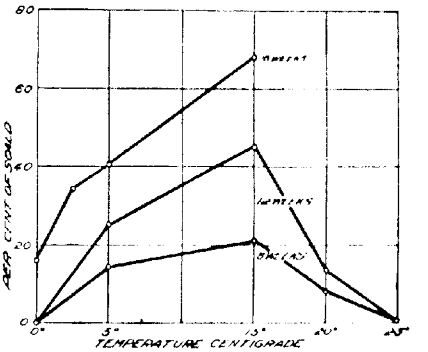

FIG. 10.—Graphs showing the effect of temperature on apple scald at the end of 8, 12, and 16 weeks. The apples were Arkansas from Middletown, Va. They were picked and packed on October 17 and placed in commercial cold storage the following day. They were removed from storage on December 4 and the above experiment started the same day.

AIR-COOLED CELLAR STORAGE

It has already been pointed out that in the experimental storage boxes apple scald was prevented at all temperatures from 0° to 30° C. by a gentle air movement. Other experiments were made under more nearly commercial conditions, in which air-cooled cellar storage was compared with commercial cold storage. The experiment was made at Wenatchee, Wash. In the fall the door and window of the cellar were kept open at night and closed in the day, and throughout the winter frequent ventilation was given. Hygrothermograph records showed that in October the average temperature of the cellar was 12° C. (53.6° F.) and the average relative humidity 60 per cent; in November the average temperature was 8° C. (46.4° F.) and the average relative humidity 78 per cent. From the first of December to the middle of March the temperature stood fairly constantly at 5° C. (41° F.) and the relative humidity at 86 per cent. In the cold-storage plant the average temperature for November was 2.5° C. (36.5 °F.) and the average relative humidity 84 per cent; for December the average temperature was 0.28° C.

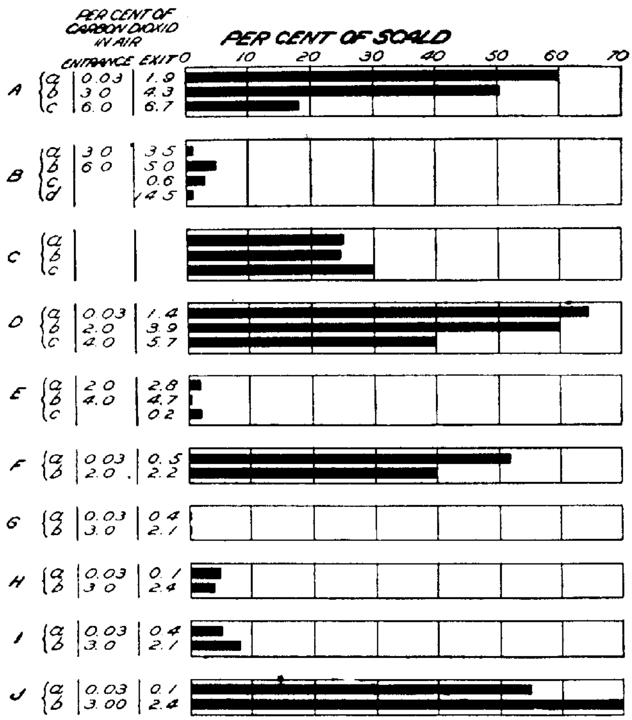

FIG. 11.—Graphs showing the relation of carbon dioxid to apple-scald production. The percentage of scald is shown by the length of the bars, and each group of bars (A, B, etc.) represents a particular experiment. In cases where the air was kept at a practically constant composition by renewal, the fresh air with or without carbon dioxid was introduced continuously at a rate such that a volume of air equal to that of the container was carried in once in 24 hours. In cases where the air was stirred, the circulation was accomplished by means of a rotary air pump. The air was kept practically saturated with moisture in all of the experiments. Five apples were used in each test.

A. The apples used in the experiment were of the lot described in the legend for figure 5. They were held in sealed jars with air slowly renewed. The results were obtained after 6 weeks storage at 15° C.

B. Same treatment as in (A), but the air was circulated constantly with an air pump. In (a) and (b) the air was slowly renewed but in (c) and (d) the circuit was entirely closed. In (c) the air was circulated over soda lime and water and in (d) over water only.

C. Apples of the lot described in the legend for figure 5 but held in cold storage 8 weeks before starting the experiment. The results were obtained after 3 weeks storage at 15° C. (a) Jar as moist chamber with a ½-inch hole in the top. (b) as in (a) but with jar inverted placing the hole at the bottom. (c) As in (a) but with soda lime and water in the bottom of the jar.

D. The apples used in the experiment were of the lot described in the legend for figure 3. [The apples were held in sealed jars with air renewed slowly.] The results were obtained after 8 weeks storage at 15° C.

E. Same treatment as in (D) but air circulated constantly with an air pump.

F. Same treatment as in (D) but at 0° C. for 16 weeks.

G. The apples used in the experiment were of the lot described in the legend for figure 9. They were stored at 2½° C. in sealed boxes with the air slowly renewed and also stirred with an air pump. The results were obtained after 20 weeks storage.

H. Same treatment as in (G) but with the apples held at 0° C. for 20 weeks, stored in sealed jars with air renewed slowly but not stirred.

I. The apples used in the experiment were of the lot described in the legend for figure 10. They were stored at 2½° C. in sealed boxes with the air slowly renewed and also stirred with an air pump. The results were obtained at the end of 20 weeks.

J. Same treatment as in (I) but the apples held at 0° C. for 20 weeks stored in sealed jars with air renewed slowly but not stirred.

(32.5° F.) and the average relative humidity 84 per cent; for January and February the average temperature was 31° F, and the average relative humidity 78 per cent, and for March the average temperature was 34° F. and the average relative humidity 95 per cent. In the cellar there was some daily variation in both temperature and humidity, while in cold storage both were quite constant.

Apples that had been carefully selected as to uniformity in size and maturity were divided into several lots, part of them being placed in cellar storage, part in commercial cold storage, and part moved from one storage condition to the other. In experiment A 2 boxes and in experiment B from 4 to 10 boxes of apples were used in each test. The apples were boxed in the usual manner. The results are given in Table X and show the percentage of scald developed after the given treatment was followed by 5 days' storage at 20° C.

TABLE X.—*Development of apple-scald in air-cooled cellar storage and in commercial cold storage*

Experiment No.	Variety and treatment.	Percentage of scald.			
		Rome Beauty.	Stayman Winesap.	Grimes.	
				After 17 weeks.	After 24 weeks.
	RATHER IMMATURE ROME BEAUTY AND STAYMAN WINESAP APPLES.				
A1	In cold storage continuously for 23 weeks	20	65		
A2	In cellar storage continuously for 23 weeks	15	0		
A3	In cold storage for 9 weeks; then in cellar storage for 14 weeks	40	30		
A4	In cellar storage for 9 weeks; then in cold storage for 14 weeks	0	0		
A5	In cold storage for 16 weeks; then in cellar storage for 7 weeks	95	90		
A6	In cellar storage for 16 weeks; then in cold storage for 7 weeks	40	0		
	HEAVILY IRRIGATED GRIMES APPLES.				
B1	Cellar storage for 17 weeks			16.8	
B2	Cold storage for 17 weeks; then in cellar storage for 7 weeks			65.0	88
B3	Cold storage for 19 weeks; then in cellar storage for 5 weeks				62
B4	Cold storage for 10 weeks; then in cellar storage for 14 weeks				14
B5	Cold storage for 5 weeks; then in cellar storage for 19 weeks				6

The apples in cellar storage ripened more rapidly than those in cold storage, particularly during the first part of the season, but in all cases there was less scald under the former condition than under the latter. With apples transferred from one condition to the other the amount of

scald varied with the length of time held under cold-storage conditions. Apples shifted in either direction during the first 9 weeks of storage seemed to derive a benefit from the shifting itself, thus furnishing further evidence that temperature changes may aid in removing scald-producing agencies.

VENTILATION IN COMMERCIAL COLD STORAGE

Experiments were made to determine the effect upon the development of apple-scald in cold storage of different kinds of packages and different amounts of air circulation. The results are given in Table XI.

TABLE XI.—*Influence of package and ventilation upon the development of apple-scald in cold storage*

Experiment No.	Variety and treatment.	Percentage of scald. Dec. 19. Barrel.	Dec. 19. Box.	Dec. 22. Barrel.	Dec. 22. Box.	Tight barrel.	Ventilated barrel.
	GRIMES.						
A1	At 0° C. (32° F.) Practically no ventilation.	2	0	45	35	......	......
A2	At 2.5° C. (36.5° F.) Some ventilation.	35	3	65	8	......	......
	ARKANSAS.						
B1	At 2.5° C. (36.5° F.)	......	......	......	......	80	50
B2	At 0° C. (32° F.)	......	......	......	......	70	25
B3	At 0° C. (32° F.)	......	......	......	......	60	30
B4	At 0° C. Room aired a few times	......	......	......	......	35	......
	At 0° C. Room not aired	......	......	......	......	70	......

EXPERIMENT A.—The apples used were Grimes, from Virginia, picked on September 7, and placed in commercial cold storage September 8. Part were packed in tight barrels and part in boxes. The apples were removed from storage on December 19, the packages opened, and held at a temperature of 18.3° C. (65° F.) for three days.

EXPERIMENT B.—Arkansas apples from Middletown, Va., picked on October 17, and stored in commercial cold storage on October 18, were used in this experiment. Part of the apples were packed in tight barrels of the usual commercial form and the others in similar barrels with holes for ventilation. Fifteen slits ⅜ inch by 4 inches were cut in each barrel. The apples were removed from storage on February 18 and held at a temperature of 20° C. (68° F.) for three days before taking the final notes.

In all cases the open packages had less scald than the tight ones, averaging about half as much. With the Grimes apples held in an unventilated storage room the fruit in the boxes was scalded practically as badly as that in the barrel; but in those held in a poorly ventilated room the box apples were practically free from scald.

Further evidence of the beneficial effects of storage ventilation is found in experiment B4 (Table XI), the apples in the room without ventilation having twice as much scald as those in the room having an occasional airing.

Cold-storage men who make a practice of opening up windows and doors when weather conditions will permit and allowing outside air to sweep through the storage rooms for a short period of time report great benefit in the way of the prevention of apple-scald.

DELAYED STORAGE

From a study of Tables IX and X it is evident that shifting apples from a higher to a lower temperature and from a lower to a higher one were not equally beneficial in scald prevention, the former always giving much better results. In experiments 1 and 2 of Table IX there was much less scald on apples stored first at 5° C. and then at 0° C. than on those stored first at 0° C. and then at 5°. Also the contrast of No. 3 and 5 with No. 4 and 6 in A of Table X shows that there was less scald on the apples stored first in cellar storage then in cold storage than on those moved from cold storage to cellar storage.

In other experiments the effect of delayed storage at higher temperatures was tested. The results are given in Table XII.

TABLE XII.—*Effects of delayed storage upon apple scald*

Experiment No.	Variety and package.	Treatment	Percentage of scald.	
			After 17 weeks	After 20 weeks
A1	Grimes apples in boxes stored at Wenatchee, Wash.	Stored at once; in cold storage for 19 weeks.	38	. . .
A2	. . . . .do.	Delayed storage[a].	15	. . .
B1	York Imperial apples from Vienna, Va., stored in barrels at Washington, D. C.[b]	To cold storage the day after picking.	. . .	25
B2	. . . . .do.	In shade in headed barrel for 6 days; then in cold storage.	. . .	8
B3	. . . . .do.	In sun in headed barrel for 6 days; then in cold storage.		10
B4	. . . . .do.	In shade in open boxes (during delay) for 6 days, then in cold storage.		3
B5	. . . . .do.	In shade protected from wind in headed barrel for 12 days, then in cold storage.		52
B6	. . . . .do.	In shade in unheaded barrel for 12 days, then in cold storage.	. . .	20
B7	. . . . .do.	In shade in open boxes (during delay) for 12 days; then in cold storage.	. . . .	20

[a] During the delay the apples were held in boxes in a shaded, well-aired place. The average maximum day temperature was 23° C. and the average minimum night temperature was 5° C. The apples were delayed 2 weeks and then held in cold storage for 17 weeks.

[b] The maximum outdoor day temperatures during the delay averaged 18.7° C., and the minimum outdoor night temperature averaged 3.4° C.

The amount of scald was reduced by delayed storage in all of the different experiments, with but one exception. This exception was with apples held in a tight-headed barrel in a protected place for 12 days. Apples held in boxes for 6 days and then repacked were practically free from scald, and apples delayed in open boxes or in barrels for 12 to 14 days developed less scald than those stored immediately. The results indicate that the effect of delayed storage upon apple scald will depend largely upon the amount of ventilation the apples receive during the delay. The original maturity of the apples would probably also have a modifying influence. The writers wish to be distinctly understood as making no general recommendation in favor of delayed storage. The temperature experiments already reported show the great importance of immediate cooling as a means of scald prevention, and this is the phase of the subject that should receive the greatest emphasis. They are convinced, however, that with any apples lacking the full degree of color and maturity that might be most desirable (this would include a large part of the average eastern crop) scald may be reduced by a few days' delay in open well-aired packages before the fruit is placed in commercial cold storage, and that if during this delay the fruit can be kept as cool as 5° C. (41° F.) or even 10° C. (50° F.) little or no increase in rot will result from it. They consider that the results that have been obtained from the various apple-scald experiments furnish strong evidence of the value of air-cooled storage houses as a supplement to commercial cold-storage plants.

EFFECT OF GAS ABSORBENTS UPON APPLE-SCALD

The results of the foregoing experiments made it evident that apple-scald is not produced by high humidity nor by an accumulation of carbon dioxid, and yet that it is due to something that can be carried away by air currents and possibly partially taken up by absorbents, such as calcium chlorid. In a previous article the writers [1] reported experiments in which scald was reduced from 65 per cent to 10 per cent on York Imperial and Arkansas apples in commercial cold storage by adding excelsior to the usual barrel pack. Powell and Fulton [2] reported that paraffin wrappers reduced the amount of scald on apples, but that ordinary wrappers did not. The trend of the evidence in these experiments and the results already reported in the present paper led to the testing of various gas-absorbing substances. The results are given in Table XIII.

With the apples whose surfaces were only partially covered with wax scald did not occur beneath the coating; yet there was no close correlation between wax and scald patterns. The wax materials having the greatest absorbing powers apparently prevented scald on other parts of the apple, as well as on those with which they were actually in contact. There was nothing unusual in the taste of the apples under any of the conditions. In general the quality varied inversely with the amount of apple-scald.

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[1] BROOKS, Charles, and COOLEY, J. S. EFFECT OF TEMPERATURE, AERATION, AND HUMIDITY ON JONATHAN SPOT AND SCALD OF APPLES IN STORAGE. *In* Jour. Agr. Research, v. 11, no. 7, p. 287–318, 23 fig., pl. 32–33. 1917. Literature cited, p. 316–317.

[2] POWELL, G. H., and FULTON, S. H. THE APPLE IN COLD STORAGE. U. S. Dept. Agr. Bur. Plant Indus. Bul. 48, 66 p., 6 pl. (part col.). 1903.

TABLE XIII.—*Effect of gas absorbents upon apple-scald*

Experiment No.	Treatment	Percentage of scald.		
			Fruit coated with wax	Fruit with bands of wax
A1	In sealed moist chamber; air renewed slowly	67		
A2	In the open	0		
A3	In unsealed moist chamber	64		
A4	Same as No. 3, but with ½ inch of cornstarch in bottom of jar.	21		
A5	Same as No. 3, but with ½ inch of animal charcoal in bottom of jar.	1		
A6	Same as No. 3, but with apples packed in excelsior	10		
A7	Same as No. 3, but with apples packed in sawdust	0		
B1	In sealed moist chamber; air renewed slowly	81		
B2	In the open	0		
B3	In unsealed moist chamber; apples not wrapped	70		
B4	In unsealed moist chamber; apples wrapped in usual commercial manner.	70		
B5	Same as No. 4, but with wrappers impregnated with paraffin.	20		
B6	Same as No. 4, but with wrappers impregnated with vaseline.	0		
B7	Same as No. 4, but with wrappers impregnated with cocoa butter.	0		
B8	Same as No. 4, but with wrappers impregnated with paraffin (50 per cent), vaseline (50 per cent).	8		
B9	Same as No. 4, but with wrappers impregnated with beeswax (30 per cent), vaseline (70 per cent).	3		
B10	Same as No. 4, but with wrappers impregnated with cocoa butter (75 per cent), vaseline (25 per cent).	1		
B11	Same as No. 4, but with wrappers impregnated with cocoa butter (80 per cent), olive oil (20 per cent).	1		
B12	Same as No. 4, but with wrappers impregnated with beeswax (30 per cent), olive oil (70 per cent).	0		
C1	None		70	70
C2	Paraffin		20	50
C3	Vaseline		0	2
C4	Cocoa butter		0	3
C5	Paraffin (50 per cent), vaseline (50 per cent)		0	5
C6	Beeswax (30 per cent), vaseline (70 per cent)		0	3
C7	Cocoa butter (75 per cent), vaseline (25 per cent)		0	1
C8	Cocoa butter (80 per cent), olive oil (20 per cent)		1	12
C9	Beeswax (30 per cent), olive oil (70 per cent)		0	0

A.—The apples were Rome Beauty of the same lot as described in the legend for figure 8, but they were held in commercial cold storage for 12 weeks. They were entirely free from scald at the time of starting the experiment. They were stored at 15° C. in nine liter jars. The results were obtained after 12 weeks' storage.

B.—Newtown Pippins of the same lot as described in Table V, B were used in this experiment. The results were obtained after 12 weeks' storage in moist chambers at 15° C. The special wrappers were prepared by dipping the usual apple wrappers in hot waxes and oils of the given composition and then allowing them to drain and cool.

C.—All conditions were the same as in B except that part of the apples were practically covered with a thin coating of wax, others had narrow bands of wax, and still others had no wax in any form. All were wrapped with ordinary apple wrappers as in commercial packing and stored in moist chambers.

As a whole, the results in Table XIII give most remarkably clear-cut and complete evidence that apple-scald can be prevented by the absorption of the gases (other than carbon dioxid) thrown off by the apples themselves in storage. The beneficial effects of the substances used in the experiments described under (A) may have been partly due to their water-absorbing power, but this could hardly be true of those used under (B) and (C). One of the particularly striking features brought out is the fact that the various substances have had a beneficial effect in direct proportion to their absorbing power. Excelsior greatly reduced the amount of scald, but sawdust entirely prevented the disease. Paraffin is distinctly the most inactive of all the waxes and oils used, and it was the only one that did not furnish practically complete control for the disease. Apple-scald can evidently be prevented by substances having a comparatively limited capacity for taking up gases if the absorbing surfaces are placed in rather close contact with the skin of the apple.

NATURE OF APPLE-SCALD

The foregoing experiments have approached the apple-scald problem from several different angles, and the results give considerable evidence as to the real nature of the disease. Apple-scald is not necessarily an old-age phenomenon, but is due to the long-continued action of more or less abnormal storage conditions, conditions that cause the production or prevent the elimination of certain waste products. Most varieties of apples may be exposed to such unfavorable conditions for several weeks without developing scald and without showing any tendency to the disease if later stored under more nearly normal conditions; but they finally reach a certain critical period at which time they are not scalded, yet have developed a tendency to scald that can not be eradicated by removing the agencies that were originally responsible for the trouble. In the experiment reported in Table VIII, B, apples that were held under conditions favorable to scald for eight weeks showed no sign of the disease when removed to a warm temperature for a few days, yet these apples developed scald later, under storage conditions that did not produce scald on fruit that had never been exposed to unfavorable conditions. With apples that have been shifted from one storage place to another it is evident that the conditions existing at the time of the development of scald may not be the ones that are responsible for the occurrence of the disease.

Apple-scald seldom, if ever, becomes evident while apples are held continuously at 0° C. (32° F.), but cold-storage apples may be found to be badly scalded after a few days at a higher temperature. As was pointed out in an earlier paper,[1] the real cause of this sudden appearance of the scald is not the sudden change of temperature. The disease already existed, but the cells were unable to carry out their death processes while a temperature of 0° was maintained.

[1] BROOKS, Charles, and COOLEY, J. S. EFFECT OF TEMPERATURE, AERATION, AND HUMIDITY ON JONATHAN-SPOT AND SCALD OF APPLES IN STORAGE. *In* Jour. Agr. Research, v. 11, no. 7, p. 287-318, 23 fig. pl. 32-33. 1917. Literature cited, p. 316-317.

SUMMARY

The foregoing experiments furnish conclusive proof that apple-scald is a preventable disease. The following are some of the more salient facts that have been experimentally established.

(1) Well-matured apples are much less susceptible to scald than immature ones.

(2) Apples from heavily irrigated trees scald worse than those from trees receiving more moderate irrigation.

(3) The rapidity of development of apple-scald increases with a rise in temperature up to 15° or 20° C., the optimum often shifting from 20° to 15° C. during the storage period.

(4) Apple scald has not occurred at temperatures of 25° or 30° C.

(5) It has been found possible to store apples in air saturated with water vapor without the development of scald. In several different experiments scald was considerably reduced by decreasing the humidity, but the beneficial effects were apparently not entirely due to the decreased moisture in the air.

(6) Accumulations of carbon dioxid (1 to 6 per cent) have not favored the development of apple-scald, but tended to prevent it.

(7) Apples susceptible to scald have been made immune by storing for a few days in an atmosphere of pure carbon dioxid.

(8) Increasing the percentage of oxygen in the air has not given consistent beneficial effects upon apple-scald.

(9) A constant air movement of from ⅛ to ¼ mile per hour has always either entirely prevented apple-scald or reduced it to a negligible quantity. The intensity of the air movement was apparently more important than the continuity and the circulation of the air more important than its renewal.

(10) Scald has been greatly reduced by shifting apples from one temperature to another. The beneficial effects are attributed to the aeration of the apple tissue thus obtained.

(11) Thorough aerations during the first eight weeks of storage have been more helpful than later ones.

(12) Apples have scalded less in air-cooled cellar storage than in unventilated commercial cold storage.

(13) Apples packed in boxes or ventilated barrels have scalded much less than those in tight barrels, especially when the storage room received an occasional ventilation.

(14) Scald was greatly reduced on rather immature apples by a delay in storing, if the fruit was well aerated during the delay, but was increased by the delay if held under conditions that allowed little or no ventilation.

(15) Ordinary apple wrappers have had no effect on apple-scald, and paraffin wrappers but little; but wrappers soaked in various mixtures of olive oil, cocoa butter, vaseline, or beeswax have entirely prevented apple-scald.

(16) Apple-scald is due to volatile or gaseous substances other than carbon dioxid that are produced in the metabolism of the apple. They can be carried away by air currents or taken up by various absorbents.

ANGULAR-LEAFSPOT OF TOBACCO, AN UNDESCRIBED BACTERIAL DISEASE[1]

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INTRODUCTION

About the first of August, 1917, the Virginia Experiment Station received a petition from 52 tobacco growers in Halifax County, asking assistance in combating a tobacco disease which threatened serious losses to the crop. Diseased tobacco plants (*Nicotiana tabacum*) were later received from a correspondent at South Boston, the leaves of which were covered with spots which were different from any previously seen by us, the most distinctive feature being the irregularly angular shape. Numerous motile bacteria were found in crushed tissue mounts and freehand sections of spots, and the organism was readily obtained in pure culture from poured plates of beef-peptone agar. The same organism was obtained later from material which the writers collected in the field from five different places in Halifax County.

Several inspection trips were made during the remainder of the season of 1917. On August 10 the disease was found on the tobacco plants in most of the fields along the road between South Boston and Republican Grove, a distance of 30 miles. It was found later in the northern part of Halifax County, at Clarkton and other points, in the southern part of Campbell County, at Brookneal and Naruna, and at Charlotte Court House, in Charlotte County. Inquiries through county agents extended the distribution to include Mecklenburg, Pittsylvania, Henry, and Patrick Counties, involving the greater part of the flue-cured-tobacco belt in Virginia.

FIELD APPEARANCE OF THE DISEASE

The epiphytotic was well advanced by August 10. Many fields were found in which practically every plant was affected, and in some fully 50 per cent of the crop was estimated by the growers to be unfit for harvest. Late plantings were found to be less severely spotted than the early plantings, and the most forward and vigorous plants were invariably more seriously affected than the less vigorous ones.

The distribution of the spots on the plants was a distinctive feature and one that readily separated them from "frogeye" (caused by *Cerco-*

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Journal of Agricultural Research, Washington, D. C.
rj

Vol. XVI, No. 8
Feb. 24, 1919
Key No. Va. (Blacksburg)-2

spora nicotianae E. and E.). The heaviest spotting was found on the top and middle leaves, while the bottom or sand leaves were but slightly affected. Frogeye, on the contrary, is found chiefly on the sand leaves. The field evidence indicated that the vertical distribution of the spots on the plants was determined by their stage of growth at the time of infection, and that leaves which had attained a certain stage of growth were not susceptible to infection. In some fields the infection was heaviest on the top leaves and in others on the middle leaves. Frequently the spots were found to be most numerous on one side of the plants, indicating the probable dissemination of the inoculum by wind-blown rain.

The consensus of the statements of the farmers placed the first appearance of the spotting between the third and fourth weeks in July, following a protracted period of rainfall. The tobacco at this time was at about the stage for topping. No one had seen any of the spotting earlier in the season, and there had been no evidence of it in the seed beds. One farmer who had planted two fields from the same seed bed stated that the disease was much worse in the field on new ground than on old ground. There was no evidence from any source that continuous cropping with tobacco, as practiced on many farms, had been conducive to heavier infection.

Some of the farmers had been troubled with the disease in the previous year, 1916, and a few stated that they had seen it occasionally over a period of 10 or 12 years, but never so generally destructive as in 1917. Prof. T. B. Hutcheson, of the Virginia Experiment Station, informs us that he has known this spotting in Charlotte County for 12 or 15 years.

Opinions among the farmers as to the cause of the disease were centered on the wet weather, the fertilizer, especially the supposed deficiency in potash, and the seed. The disease was found on both the flue-cured and sun-cured types of tobacco, and no differences in the susceptibility of varieties were apparent.

Evidence that the disease is not occasioned by lack of potash and that it is not a fertilizer phenomenon, except in a secondary way, was obtained from a study of the distribution of the spotting on the fertilizer plots at the experimental substation at Charlotte Court House. Early in September the disease was prevalent on all plots which had received applications of acid phosphate alone or in various combinations with sulphate of potash and nitrate of soda. It was the opinion of several observers who went over these plots that they were uniformly spotted. None of the spotting was present, however, at this time, on any plots which had had no applications of phosphorus and which had received only nitrate of soda or sulphate of potash, or both. There was no spotting on the control plots. The tobacco plants on those plots which had received phosphorus were larger, more vigorous, and matured three weeks earlier than those which had had no phosphorus. The superintendent of

the substation informed us that the tobacco on these backward plots became spotted later with the advent of additional rainfall and cool nights, and that the second growth tobacco from the early harvested plots also became diseased.

CHARACTER OF LOSSES

A demonstration acre of tobacco at the substation at Charlotte Court House was severely spotted in 1917, much more so than in any previous years. The yields from this acre were obtained to determine the variation in yield and grade between 1917 and the average of preceding years. The data obtained are included in Table I. The yield of the average year was determined from demonstration acres for the years 1913, 1914, and 1915. Complete data for 1916 were not available, but the total yield for this year, 1,005 pounds, shows a close agreement with the three preceding years. The effect of the disease is shown both in a reduction in yield and in grade. The yield from the acre in 1917 was 212 pounds less than that of the average year, or approximately 80 per cent of the average. The yields in the different grades for 1917 show a loss in weight in all of the three highest grades and a strong increase in the lowest grade. There were approximately 40 per cent more sand lugs in 1917, in proportion to the higher grades, than in the average year, and the percentage of longs was slightly greater. The gain in the sand lugs was made up by losses in the two middle grades, good lugs and shorts. The total loss in weight was 20 per cent, and the loss in grade approximately 40 per cent.

Table I.—*Variation in yield and grade between severely spotted tobacco in 1917 and the average of three preceding years of light spotting*

Grade.	1917	Average year.	1917	Average year.	Difference between 1917 and average year.	
	Pounds.	*Pounds.*	*Per cent.*	*Per cent.*	*Pounds.*	*Per cent.*
Sand lugs	495	205	58.9	19.4	+290	+39.5
Good lugs	....	290	....	27.6	−290	−27.6
Shorts	155	346	18.5	32.9	−191	−14.4
Longs	190	211	22.6	20.1	−21	+2.5
Total	840	1,052	....	....	−212	−20.2

DESCRIPTION OF THE SPOTS

The spots are found only on the leaves, none on stems or floral parts. They are scattered over the entire leaf surface, between the larger veins, or are crowded in irregular groups. They are usually bordered by viens which act as barriers against further enlargement. More than 500 spots may be counted on the average leaf of a heavily infected plant. They are about equally prominent on the upper and lower leaf surfaces. The

size of the spots varies from a pinhead up to 8 mm. in diameter at the widest part, and the average diameter of the mature spot is 4 mm. The most striking feature is the irregularly angular shape and the uneven jagged outline (Pl. 25-27). The center of the spot is tan or reddish brown, with a darker thin border and often a suggestion of zonation which is never conspicuous. A small, dark center is usually seen. In earlier stages the spots are darker in color, almost black [1] at first, and are circular or only slightly angular (Pl. 25, A). The center of the spot becomes dry and thin with age, paler in color until almost white, and may drop out, leaving irregular holes which are sometimes so numerous with the confluence of spots that a skeleton leaf composed only of the viens remains. Most of the tobacco is harvested before this stage is reached. No sharply defined halo is present, but a narrow clear zone on the border is seen by transmitted light. The tissue bordering the spots is yellowed, but this diffuses gradually into the normal green. Usually the spots are more numerous on one side of the midrib.

In stained sections of fixed material the organism is found in great numbers throughout the shrunken tissue included in the spot. It is found both within and between the cells, and vacuolated cells are completely filled with it.

INOCULATION EXPERIMENTS

Proof of the pathogenecity of the organism isolated from leafspot material was obtained through inoculations on seedling tobacco plants (Warne variety). This work was carried on in the greenhouse during the winter months. In all, some 150 plants were inoculated, and fully 96 per cent developed spots. All five isolations of the organism produced infection. Infection was readily obtained by atomizing the plants with aqueous suspensions of the organism, by swabbing the leaves with the cotton plug of bouillon cultures and by puncture with contaminated needles. It was found necessary to place the plants in moist chambers for 24 hours subsequent to inoculation. Some plants which were inoculated and left in the open greenhouse failed to develop any spots, and none of the many control plants became infected. No leaf injury is necessary for infection. Apparently the organism gains entrance through the stomata on either the upper or lower surface of the leaf. The inoculum has been recovered in pure culture a number of times, and these recoveries have been used for reinfections. Secondary infections have never developed, but this is a common experience with plant pathogens under the dry atmospheric conditions of the greenhouse.

As many as 200 spots were obtained on a single leaf through inoculation with the atomizer, but the average ran much lower than this. Still heavier infections were obtained by swabbing with contaminated cotton plugs. The spots obtained were typical of the spots seen in the field, but were smaller. They averaged about 1.5 mm. in diameter, and

[1] One farmer stated that his first impression of the spot was that someone had spattered ink on the leaves.

many were no larger than 0.5 mm., mere pin pricks. The spots were frequently grouped on a limited area of the leaf and were often found on one side of the midrib only.

The discrepancy in size between the field spots and those developed in the greenhouse is apparently due to the difference in the size and vigor of the plants. The plants did not grow vigorously in the greenhouse and at maturity were not more than half as large as plants in the field. The largest spots in the greenhouse were always found on the most vigorous plants and on the most rapidly growing leaves. The incubation period was also shortest with the same plants and leaves. This varies between 4 and 10 days, with the average about 7 days. When plants which have developed a number of leaves are inoculated, the first spots are seen on one or two leaves near the top and intermediate in age. Later, within a few days, spots may appear on two or three older leaves immediately below these, but no spots develop on old, full-grown leaves, nor on very young ones. Young leaves become infected, however, when the inoculum is rubbed in with the fingers or a cotton plug. The young leaves are closely set with trichomes, and these seemingly serve as a mechanical protection against inoculation with the atomizer; the spray is caught and retained on them. The spots attain their maximum size within a few days after their appearance. They are largest on the younger leaves and may be mere pin pricks or flecks on the older leaves.

TABLE II.—*Results from the inoculation of tobacco plants with the angular leafspot organism*

Plant No.	Number of spots per leaf on leaf No.[a]				
	1	2	3	4	5
1		2			
2		14	13	1	
3	1	1		2	
4	5	68	19	**33**	
5			5	1	
6	14	29	17	21	**9**
7	157	8	39		**30**
8			51	14	**6**
9		44	63	23	
10	1	[illegible]	5		
11	1	18			
12					
13	3	5	4	**41**	
14	6	3	4		
15					
16	1	1			
17	58		37		
18	30		23	14	
Total spots	277	193	280	76	
Total flecks				**74**	**45**

[a] Leaves are numbered from the top downward. The plants bore from 10 to 14 leaves. Bold-face figures indicate flecks or spots that are very small and are visible only in transmitted light.

The records of one inoculation series are given (Table II) chiefly to show the vertical distribution of the spots with reference to the position of the leaves and their relative ages. These plants were inoculated on January 16, 1918, with an atomizer containing an aqueous suspension of a strain of the angular-leafspot organism isolated from material from Republican Grove, Va., on August 10. The plants were covered with moist chambers for 12 hours subsequent to inoculation. They were at the blooming stage and were topped just before inoculation. The spots were first visible on January 22, and the counts were made on February 1.

Table II shows that the spots were about equally distributed over the first, second, and third leaves, with a few on the fourth leaves and none on those older and lower on the stem. Flecks developed on the fourth and fifth leaves, but not on younger or older leaves.

COMPARISON OF ANGULAR-LEAFSPOT WITH OTHER LEAFSPOTS OF TOBACCO

The angular-leafspot can not be assigned with certainty to any of the previously described tobacco leafspots of bacterial causation. It has some features in common with the "whitespot" of Delacroix (*2*, *3*),[1] caused by *Bacillus maculicola* Del., but the descriptions of this disease and of the organism are too meager to afford an adequate basis for comparison. "Blackrust," a disease of Deli tobacco described by Honing (*4*), differs from angular-leafspot in several important features, and the causative organism, *Bacterium pseudozoogloeae* Honing, is readily distinguished from the angular-leafspot organism.

The spot which Wolf and Foster (7) have recently described under the name "wildfire" from North Carolina appears to differ strikingly from the disease under discussion. The most noteworthy points of difference being found in the broad, distinct halo which borders the wildfire spots, in their circular form and zonated interior, and in size. Wildfire spots are 2 to 3 cm. in diameter, while those of the angular-leafspot are only 4 mm., on the average. Some contrasting features between *Bacterium tabacum* Wolf and Foster, the wildfire organism, and the angular-leafspot organism are given in Table III. Features in common between the two diseases are found in their sudden appearance and rapidity of spread, and in the relation between rainfall and epiphytotics, although this seems a common feature of bacterial leafspots of tobacco. It seems quite probable that the disease to which Wolf and Foster refer as "speck" is identical with our angular-leafspot. They state that speck is caused by a lack of potash.

[1] Reference is made by number (italic) to "Literature cited," p. 227–228.

TABLE III.—*Comparison of Bacterium angulatum and Bact. tabacum*

Bact. angulatum.	*Bact. tabacum*
1. Size, $0.5 \times 2\text{–}2.5\ \mu$	Size, $1.2 \times 3.3\ \mu$.
2. 3 to 6 polar flagella	1 polar flagellum.
3. Liquifies gelatin rapidly	Liquifies gelatin slowly.
4. Forms acid with saccharose and dextrose.	Forms acid with saccharose, dextrose, lactose, and glycerin.
5. No growth in closed arm of fermentation tubes.	Growth in closed arm of fermentation tubes containing dextrose and saccharose.

An unsigned note in the Yearbook of the Virginia Department of Agriculture and Immigration (5) contains a report of a field investigation of a spotting of tobacco leaves (evidently angular-leafspot) which was prevalent in Pittsylvania and Mecklenburg counties in 1917. The spotting is assigned to microorganisms, and it is stated that the disease becomes serious only under certain conditions which affect the resistance of the tobacco plant. The most important of these are considered to be rainfall and excess of nitrogen in the fertilizer or soil. A liberal supply of potash is said to decrease the severity of the disease, but considerable damage was noted even with heavy potash applications. The same disease is said to occur in North Carolina and Maryland.

Two other leafspots, the causes of which have not been assigned to bacteria, and which appear somewhat similar to angular-leaf spot, are "rust" of tobacco in Connecticut (*1, p. 366–367, pl. 31, b, c*) and *Pockenkrankheit* (*6, p. 56*) of tobacco in Europe. Clinton's figures of rust, especially that shown in his Plate 31, c, look much like angular-leafspot. He states that rust is usually found on leaves affected with calico and believes it may be caused by scorching of the sun. *Pockenkrankheit* is ascribed to excessive transpiration accompanying decreased water supply.

OCCURRENCE OF THE DISEASE

It seems quite probable that angular-leafspot is a disease of rather general distribution and one of long standing which has not been sufficiently destructive to attract extensive notice, except in seasons unusually favorable for its development. Our experience indicates that rainfall accompanied by subnormal temperatures favors infection by the leafspot organism and that any combination of conditions which promotes a rapid, succulent growth of the host favors the development of the organism within the leaf tissue. It seems quite probable that infection may be common in some seasons, but that in the absence of the predisposing growth factors little development ensues, and no damage results.

DESCRIPTION OF THE ORGANISM

The caustive organism of angular-leafspot appears to be an undescribed species, and a description is therefore appended.

Bacterium angulatum, *n. sp.*

As it occurs in the plant and also on media, the organism is a short rod with rounded ends, single or in pairs, 0.5 μ wide by 2 to 2.5 μ long. No spores are produced, and no capsules have been demonstrated. It is motile by means of a small tuft of flagella at one pole, demonstrated by the Van Ermengen silver-nitrate method. The number of flagella varies from about three to six, and they are slightly longer than the body of the bacterium. It stains readily with the ordinary dyes, and is Gram-negative and not acid-fast.

TEMPERATURE RELATIONS

The best growth is obtained at temperatures between 17° and 20° C. There was no growth at 37.5° C.

CULTURAL CHARACTERS

AGAR PLATES.—Colonies are visible in 48 hours at 20 to 22° C. They increase slowly in size, being less than 1 mm. in diameter at three days. After seven days the largest are 4 mm. in diameter and the average about 3 mm. The maximum size attained is 8 mm. They are round, smooth, convex, shining, opalescent at first, later becoming dull white with a slight creamy cast and develop an opaque center with a clear margin. They are finely granular under the compound microscope, with a slightly undulate margin. Buried colonies are lenticular.

AGAR SLANTS.—Growth is slight in three days, the line of the stroke being about 1 mm. broad, and is not more than 5 mm. broad after one month. The growth is filiform, slightly raised, shining, smooth, and slimy. Considerable white sediment is formed at the base. The medium attains a slight pale-green fluorescence.

GELATIN PLATES.—Colonies are visible in 48 hours as small points similar to those on agar. Liquefaction is rapid, beginning in cuplike hollows in 48 hours. The cupules are 5 to 10 mm. broad in 3 days. Thickly sown plates are completely liquefied in 48 hours.

GELATIN STABS.—Liquefaction is infundibuliform and begins in 24 hours. As liquefaction progresses, the upper part becomes stratiform, and the lower maintains the blunt funnel form. Liquefaction is complete within 15 days at 18° to 20° C.

BEEF BOUILLON.—Uniform heavy clouding occurs within 48 hours. No surface scum or pellicle is produced, and there are no zoogleæ. A grayish precipitate forms in old cultures.

BEEF BOUILLON WITH SODIUM CHLORID.—Two per cent sodium chlorid produced only a slight inhibition of growth in 48 hours. Heavy clouding was present at seven days with 2 per cent of sodium chlorid, but growth was practically inhibited with 4 per cent of the salt.

POTATO CYLINDERS.—The form of growth is similar to the agar slant but with a slight dull yellow pigment.

MILK.—Inoculated milk clears slowly and without coagulation. The protein is digested. Clearing begins within seven days in definite layers from the top downward, and is complete within three weeks. The liquid is only faintly translucent at this time and is near Ridgeway's pale fluorite green.

LITMUS MILK.—Lavender-colored litmus milk becomes blue from the top downward in definite layers. The color change begins on the second or third day and is complete within 14 days. During two months the medium remained dark blue and liquid.

FERMENTATION TUBES.—The tests were made in basal solutions of 1 per cent peptone, to which was added 1 per cent of the following carbon compounds: Saccharose, dextrose, lactose, maltose, glycerin, and mannit. Clouding occurred in the open ends of all tubes in 48 hours, but the closed ends remained clear with a distinct line across the inner part of the U. Tests with neutral litmus paper gave an acid reaction with saccharose and dextrose, while the others were neutral or faintly alkaline. No gas was formed with any of the compounds.

The tests for acid production with dextrose and saccharose were repeated, with 100-cc. portions of 2 per cent of each in 2 per cent peptone water. After 10 days the reaction was determined with phenolphthalein as the indicator. Both solutions showed acid production in excess of the controls as follows: Saccharose control, +6.6, saccharose inoculated, +11.0; dextrose control, +8.8, dextrose inoculated, +22.6.

REDUCTION OF NITRATES.—Nitrates are not reduced.

INDOL.—A moderate indol production was obtained in Dunham's solution.

USCHINSKY'S SOLUTION.—Clouding was evident after 48 hours and was only moderate at seven days. The medium did not change color and no scum or pellicle was formed.

AEROBISM.—The organism appears to be strictly aerobic.

Following the chart of the Society of American Bacteriologists, the group number is 211.23220[1] 33.

SUMMARY

A leafspot disease of tobacco which was prevalent in the flue-cured belt in Virginia in 1917 is described under the name "angular-leafspot." The disease has apparently been present to some extent for several years and may have a wide distribution.

The disease is caused by a specific organism, which is described as "*Bacterium angulatum*." Rainfall is an important aid to infection, and the development of the organism within the tobacco leaf is apparently dependent to a marked degree on those predisposing factors which promote a rapid, vigorous growth of the host.

The disease produced losses in both yield and grade. These were calculated in one field as a 20 per cent reduction in yield and a 40 per cent reduction in grade.

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[1] A very slight fluorescence is imparted to the medium with agar stroke.

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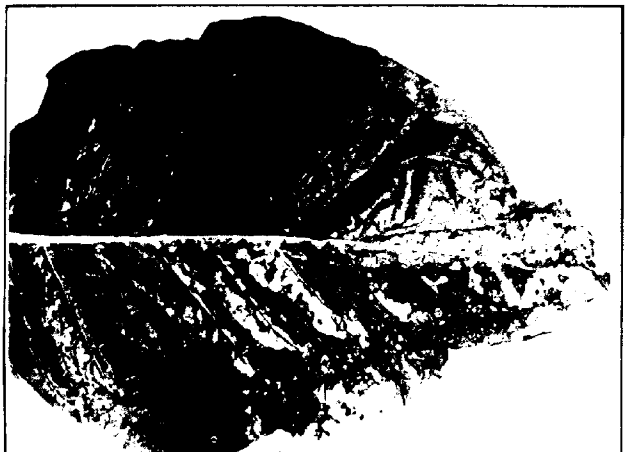
PLATE 25

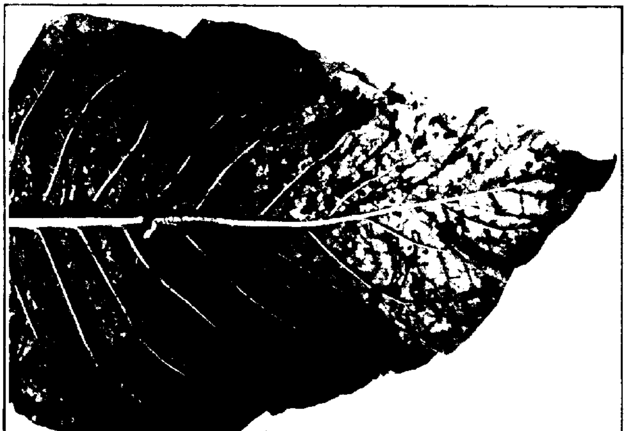
A.—A tobacco leaf showing an early stage of the angular-leafspot.
B.—Angular leaf spots on a tobacco leaf. About natural size.


A


B



A



B

PLATE 26

A.—Upper surface of a tobacco leaf affected with the angular-leafspot.
B.—Lower surface of a tobacco leaf affected with the angular-leafspot.

PLATE 27

A.—Angular leaf spots on a tobacco leaf as seen in transmitted light.

B.—Atypical angular leaf spots on a narrow leaf of tobacco. The spots are blanched and rounded.

A

B